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NON-PROVISIONAL APPLICATION

FOR

UNITED STATES LETTERS PATENT

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CHARACTER RECOGNITION SYSTEM AND METHOD USING SPATIAL AND STRUCTURAL FEATURE EXTRACTION

of which the following is a specification.

PROVISIONAL PRIORITY CLAIM

Priority based on Provisional Application, Serial No. 60/252,817, filed November 22, 2000, and entitled "SPATIAL AND STRUCTURAL FEATURE EXTRACTION USING RUNS" is claimed.

BACKGROUND

1. Field

Although not so limited in its utility or scope, implementations of the present invention are particularly well suited for incorporation in automated mail processing systems to facilitate the resolution of address and other character-containing images captured from mail pieces moving on a transport system, for example. Alternative implementations may be more broadly applied in other applications requiring the resolution of unknown input alphanumeric characters.

2. Brief Description of Related Art

Character recognition techniques are typified by "feature extraction" in which features of an unknown input character are selected for extraction and comparison to a standardized set of features associated with various "ideal" representations of known characters. A degree of analogy between the selected features from the unknown character and the standardized set of features corresponding to each of one or more known characters is then determined. The known character corresponding to the features having the greatest degree of analogy to the extracted features of the input character is then selected as the output character.

Varying among different recognition techniques are the features by which characters are characterized and the methods by which features of an unknown input character are selected for extraction and comparison with standardized data corresponding to known characters. There are also differences among various

techniques as to how extracted information is represented and compared to standardized features. Several techniques, for example, involve representing character strokes by vectors having a magnitude (e.g., length in pixels) and a direction, the vectors being directionally classified with respect to a particular scan direction. In at least one such technique, vector representations of a character's strokes are classified according to type (e.g., angle). The number of representative vectors of each classification for a particular input character is then ascertained. Each standardized character having the same number of classified strokes as the vector representation of the input character is retrieved from memory. If more than one standardized character is retrieved for comparison to the input-character representation, then steps are initialized to ascertain which standardized character among the plural standardized characters possesses the highest degree of analogy with the profile of the unknown input character.

Some previous methods are also exemplified by the extraction of skeletal features. For instance, character strokes of a particular width in an input character are represented by a "stick-figure-like" representation in which the strokes are of substantially reduced width. One difficulty invited by such techniques is the signal-damaging effects of noise because, for instance, the thinner the representation of a feature, the closer in size the representation is to the magnitude of noise. Noise effects are discussed further in the summary section below.

In addition, the reliance of current character recognition techniques on a limited number of character feature types (e.g., strokes) limits the bases upon which one character can be distinguished from another. It will be appreciated that the more limited the feature types by which one character can be distinguished from another, the higher the likelihood of character misidentification.

Accordingly, there exists a need for a system of classifying character features and extracting the relevant features from an unknown input character that is resistant to the effects of noise and that increases the character feature types by which characters can be distinguished.

SUMMARY

According to a general set of implementations, alternative methods of recognizing an unknown input character include a combination of some or all of the steps to be described.

Various implementations include providing a character dictionary containing a plurality of standardized output character candidates. Each output character candidate has a corresponding standardized profile defined in terms of a unique combination of character structure types including, for instance, bars, lakes and bays and the spatial relationships between and among bars lakes and bays. For example, an idealized letter "B" could be defined in terms of one vertical bar, three horizontal bars and two lakes. A standardized letter "F" might be defined in terms of one vertical bar and two horizontal bars and perhaps one bay, for example.

In various aspects, standardized output character candidates are distinguished in terms of the quantity of each feature type that character possesses and, where necessary, the spatial relationship between and/or orientation of the various features types. For instance, both a "p" and a "q" could be defined in terms of one vertical bar and one lake. Defined in such terms, the quantity of each character type is not sufficient to distinguish a "p" from a "q." However, a basis for distinction between "p" and "q" is introduced by further defining the "p" as having a lake to the right of the vertical bar and the "q" as having a lake to the left of the vertical bar. Such information is still not sufficient, however, to distinguish between a "p" and a "b" and a "q" from a "d." More specifically, a "p" and a "b" may be defined as having a single lake to the right of a vertical bar. Similarly, both a "q" and a "d" are definable in terms of a lake to the left of a vertical bar. Accordingly, more data is required to distinguish "b" from "p" and "d" from "q." For instance, the "b" can be defined as having a lake to the lower right of the midpoint of the vertical bar or by some other spatial relationship that distinguishes it from "p."

In one aspect, a character image of an object character is captured from a

medium such as a sheet of paper or envelope, for instance. The captured character image is stored in a data storage device from which it can be selectively accessed. The identification of the captured character image depends on the extraction of lake, bar and bay features from the character image. In various aspects, lakes, bars and bays may be described, for example, by considering a character comprised of black pixels on a field or background comprised of white pixels. A lake is an area of background composed of pixel runs extending in each of a specified number of directions (e.g., vertical, horizontal and two diagonals) wherein each pixel run is bounded at either end by character (i.e., black) pixels. That is, a lake is a region of enclosed background pixels. For instance, consider the character "e" comprised of black pixels on a white field. The "e" has a white "lake" in its upper half.

The captured character image is rendered accessible to feature extraction apparatus. In a typical implementation, the feature extraction apparatus is programmed to algorithmically generate pixel-run representations of the character image and filter predetermined features in accordance with a set of extraction parameters. The feature extraction apparatus assemble a feature vector (e.g., a set of numeric data) indicative of the algorithmically extracted features.

In accordance with one set of implementations, an assembled feature vector is communicated to a comparator unit that has access to one or more character dictionaries containing standardized character feature profiles corresponding to output character candidates. The comparator unit is adapted to compare the assembled feature vector data to the data contained in the standardized character profiles in the dictionary or dictionaries to which the comparator unit has access. The comparator unit selects for output the output character candidate corresponding to the standardized profile containing data that most closely resembles the data in the assembled feature vector.

In alternative implementations, assembled character feature vectors are communicated to a neural network for identification of the characters to which they

correspond. The neural network is "trained" through a process known to practitioners of the art of computer architecture as "learning by example" according to which the neural network is fed plural variations of the same character and, during the training phase, instructed as to the desired output. For instance, during training, the neural network may be supplied with dozens, or even hundreds or more, handwritten and typed versions of the letter "A." The more disparate versions of letter "A" the neural network experiences, the greater the likelihood that the neural will correctly identify unknown input characters "A" when called upon to do so.

Implementations incorporating a neural network are particularly advantageous because they avoid the need for the manual creation of a dictionary. Such manually created dictionaries require programmers to enter large numbers of variant "stock" representations of each character on the theory that the greater the number of stock representations that exist, the greater the likelihood that a sufficiently close representation will be available for matching to the unknown input character. It will be appreciated that manually created dictionaries are more rigid and commensurately more intolerant of an unknown input character's structural deviation from a preprogrammed ideal representation. That is, unknown input characters that structurally deviate too far from entries in the menu of preprogrammed output character candidates corresponding to the unknown input character may not be accurately recognized. The use of a neural network obviates the arduous task of preprogramming countless variant character representations while substantially improving the capacity for positive character identification. Advantageously, a neural network's greater tolerance for deviation from idealized character representations renders implementations employing neural networks less susceptible to the effects of noise.

An advantage realized by implementations of the present invention is a substantial reduction in the effect noise has on feature determination as compared, for example, to methods relying upon skeletal feature extraction. By way of example, for an hypothetical magnitude of noise on the order of one or two pixels, the interference

with a skeletal feature that is itself on the order of 1 or 2 pixels wide could be profound, perhaps even nullifying of the skeletal feature. However, when relatively large, more "holistic" structures are the focus, noise on the order of 1 to 2 pixels in magnitude is negligible.

Another advantage associated with implementations of the present invention is that they increase the scope of features by which an unknown input character can be distinguished from other characters. Implementations of the present invention identify and make use of not only structures comprised of character pixels, but structures comprised of background pixels (e.g., lake and bays). The resultant increase in features introduced by the present invention facilitates more positive identification of characters.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts an illustrative character recognition system;

FIG. 2 depicts an image of illustrative character "I" comprised of pixels revealed through magnification;

FIG. 2a depicts horizontal and vertical algorithmic run-length determination scans of the image in FIG. 2;

FIG. 2b depicts a 45-degree (i.e., northeast) algorithmic run-length determination scan of the image in FIG. 2;

FIG. 2c depicts a 315-degree (i.e., southeast) algorithmic run-length determination scan of the image in FIG. 2;

FIG. 2d is a cumulative histogram of occurrences versus run length representing the run-length data accumulated through the scans depicted in FIGS. 2a through 2c for purposes of establishing an average stroke width;

FIG. 2e is a direction-specific histogram generated from the horizontal run-length data resulting from the horizontal scan represented in FIG. 2a for purposes of establishing a direction-specific stroke width;

FIG. 2f is a direction-specific histogram generated from either of the northeast and southeast run-length data resulting from either of the scans represented in FIGS. 2b or 2c for purposes of establishing a direction-specific stroke width applicable to either diagonal;

FIG. 2g is a direction-specific histogram generated from the vertical run-length data resulting from the vertical scan represented in FIG. 2a for purposes of establishing a direction-specific stroke width;

FIG. 2h illustrates a horizontal bar-extraction scan of the image in FIG. 2;

FIG. 2i depicts a vertical bar-extraction scan of the image in FIG. 2;

FIGS. 2j and 2k represent, respectively, bar extraction scans of the image of FIG. 2 along the northeast and southeast directions;

FIG. 3 depicts a character image comprised of character image pixels and including the character image character "e;"

FIG. 3a depicts the character image shown in FIG. 3 with the edge pixels shaded to facilitate identification of the image boundary;

FIG. 3b depicts the complement of the character image of FIG. 3 and two connected regions comprised of blackened background pixels, one connected region touching the image boundary and the other connected region not touching the image boundary;

FIG. 3c depicts the isolation of a lake in the complemented image of FIG. 3b by the exclusion of the boundary-touching connected region;

FIG. 3d illustrates the isolation of the boundary-touching connected region shown in the complemented image of FIG. 3b achieved by the exclusion of the connected region that does not touch the image boundary;

FIG. 3e depicts a horizontal bay resulting from a horizontal bay-extraction scan of the image in FIG. 3d that excludes horizontal pixel runs that touch the image boundary;

FIG. 3f depicts a vertical bay resulting from a vertical bay-extraction scan of the image in FIG. 3d that excludes vertical pixel runs that touch the image boundary;

FIG. 3g depicts the results of a horizontal bar-extraction scan performed on the

image of FIG. 3;

FIG. 3h depicts the results of a vertical bar-extraction scan performed on the image of FIG. 3;

FIG. 3i depicts the results of a 45-degree (northeast) bar-extraction scan performed on the image of FIG. 3;

FIG. 3j depicts the results of a 315-degree (southeast) bar-extraction scan performed on the image of FIG. 3;

FIG. 4a shows a character image including the character image character “p” comprised of black character pixels and white background pixels;

FIG. 4b shows a character image including the character image character “q” comprised of black character pixels and white background pixels;

FIG. 4c shows a character image including the character image character “b” comprised of black character pixels and white background pixels;

FIG. 4d shows a character image including the character image character “d” comprised of black character pixels and white background pixels;

FIG. 5 is a character image including the character image character “c” comprised of black character pixels and white background pixels;

FIG. 5a depicts the complement of the character image of FIG. 5;

FIG. 5b depicts the results of a horizontal bar-extraction scan performed on the image of FIG. 5;

FIG. 5c depicts the results of a vertical bar-extraction scan performed on the image of FIG. 5;

FIG. 5d depicts the results of a 45-degree (northeast) bar-extraction scan performed on the image of FIG. 5;

FIG. 5e depicts the results of a 315-degree (southeast) bar-extraction scan performed on the image of FIG. 5;

FIG. 5f depicts two horizontal bays resulting from a horizontal bay-extraction scan that excludes horizontal pixel runs that touch the image boundary from the complement

image of FIG. 5a;

FIG. 5g depicts a vertical bay resulting from a vertical bay-extraction scan that excludes vertical pixel runs that touch the image boundary in the image in FIG. 5a;

FIG. 5h shows an illustrative assembled feature vector assembled based on the extraction scan results depicted in FIGS. 5a through 5g;

FIG. 6 shows an illustrative feature vector assembled based on the data extracted from the character image character "e" shown in FIGS. 3 through 3j;

FIG. 7 depicts an illustrative character dictionary including a set of standardized character profiles;

FIG. 8 depicts a neural network being trained to recognize illustrative variations of the character "A;" and

FIG. 9 is a flowchart representation of an illustrative character recognition method.

DETAILED DESCRIPTION

The following description of a character recognition system and method, and various implementations thereof, is illustrative in nature and is therefore not intended to limit the scope of the invention or its application of uses.

Referring to FIG. 1, an illustrative character recognition system **110** includes a central processing unit (CPU) **112**; a bus **115**, through which various system components are communicatively linked; a data store **120**; image acquisition apparatus **130** (e.g., a camera and/or OCR scanner); a feature extraction unit **150**; and character recognition apparatus **170**. In one set of alternative implementations, the character recognition apparatus **170** includes a character dictionary **180** and a comparator unit **200**. In another set of alternative implementations, the character recognition apparatus **170** includes a trainable neural network **300**. Illustrative aspects implementing, alternatively, (i) a dictionary **180** and comparator unit **200** and (ii) a neural network **300** are discussed further in this description.

The character recognition system **110** implements a general methodology according to which alphanumeric characters are classified and distinguished from one another on the basis of unique combinations of certain, predefined character features and, for example, the quantity of each type of, and the spatial relationships among, analogous character features in an unknown object character. Implementations are characterized by reliance upon three main character structures predefined as bars, lakes and bays. The nature of each of bars, lakes and bays is more fully developed further in this description.

According to an illustrative implementation, an image **20i** of an object character **20** is inputted into the character recognition system **110**. For example, an object character **20** printed on paper **35** is placed in optical proximity with the image acquisition apparatus **130** and a character image **20i** is captured and stored in the data store **120** as digitized image data accessible to the feature extraction unit **150**.

The feature extraction unit **150** comprises a set of algorithms **152** adapted to operate on a character image **20i** and systematically extract its identifying features. The set of algorithms **152** includes routines for extracting bars, lakes and bays from the character image **20i** through one or more series of manipulations. Among the manipulations is the generation of pixel-run representations of the original character image **20i** inputted into the feature extraction unit **150**. Pixel-run representations are generated for each angle of a predetermined set of "scan" angles (e.g., horizontal, vertical, and two diagonals of 45° and 315°). Analyzed in this manner, each bar, lake and bay is treated as a configured "connected region" comprised of laterally adjacent pixel runs, an observation that will be more fully discussed further in this description. Furthermore, in various aspects, the generation of pixel-run representations in different directions results in the isolation and extraction of different features from the original character image **20i**. As the character image **20i** is scanned in a particular direction by an extraction algorithm, various features of the character image **20i** uniquely ascertainable from that direction are identified and tracked. As features of the character

image **20i** are extracted, data relating to each feature of a selected set of features are stored in association with an assembled character feature vector **30** in accordance with a predetermined protocol. The assembled character feature vector **30** is then rendered accessible to the character recognition apparatus **170** for identification of the unknown object character **20** corresponding to the character image **20i** inputted into the system **110** and from which the assembled feature vector **30** was derived.

An illustrative bar extraction process is explained in conjunction with FIGS. 2 through 2k. Referring to FIG. 2, a character image **20i** includes as a character image character **22** an illustrative capital "I." The character image **20i** is magnified to reveal the character image pixels **40** of which it is composed. A character image **20i** typically includes character pixels **42**, which combine to form the character image character **22**, and background pixels **44**, which form the backdrop with which the character image character **22** contrasts. The field of background pixels **44** is bounded by an image edge or boundary **45** comprised of edge pixels **47**. Although character pixels **42** and background pixels **44** can each be any color of a selected plurality of colors, for purposes of discussion and illustration, the character pixels **42** are shown in black and the background pixels **44** are shown in white. In various figures, the edge pixels **47** are shown in gray for ease of identification.

According to an implementation, the average stroke width $\mathbf{SW_A}$ of the character image character **22** within the character image **20i** from which bars are to be extracted is first determined. The average stroke width $\mathbf{SW_A}$ is useful in various aspects because the existence of a bar implies a degree of elongation in a particular direction. Accordingly, in various implementations, the determination of an average stroke width $\mathbf{SW_A}$ provides a basis for establishing the relative elongation of a run of pixels and/or a laterally connected group of pixel runs (e.g., a bar), with respect to the width of the stroke orthogonal to the run. Establishing the direction of elongation angularly orients the bar and angular orientation is one basis upon which a run or bar can be characterized.

In various implementations, the average stroke width $\mathbf{SW_A}$ is determined by determining the length of each run of character pixels **42** within the character image **20i** along each scan line **55** extending in each direction of a specified set of directions. For example, as shown in FIGS. 2a through 2c, respectively, the character image **20i** including the character image character "I" is algorithmically scanned horizontally, vertically, along a diagonal of 45 degrees (i.e., northeast) and along a diagonal of 315 degrees (i.e., southeast). The length of each pixel-run **50** of character pixels **42** lying along an algorithmic scan line **55** is determined for each direction of algorithmic scan. The scan lines **55** are indicated by the arrows in FIGS. 2a through 2c. It is to be understood that any desired number of predetermined scan directions can be specified. Accordingly, four scan directions are illustrative only and should not, therefore, be construed as a limitation on the scope of the invention as expressed in the appended claims. Moreover, in various aspects, different directional scans can occur simultaneously or sequentially.

As shown in FIG. 2a, more than a single run **50** of character pixels **42** can exist along a single scan line **55**. In FIG. 2a, there are twenty-one vertical scan lines **55**, each of which passes through thirty-six total character image pixels **40**, and thirty-six horizontal scan lines **55**, each of which passes through twenty-one total character image pixels **40**. Consider the vertical scan lines **55** passing through character pixels **42** other than the five scan lines **55** at the center of the character image character **22**. There are five vertical scan lines **55** on either side of the five center runs **50**. Each scan line **55** within the two sets of five on either side of the center runs **50** includes two vertical runs **50v**, each of which runs is five character pixels **42** in length.

In various aspects, the feature extraction unit **150** tracks such information as the quantity of runs **50**, the locations of runs **50**, the order of runs **50**, and the quantity of character pixels **42** within each run **50** and the location of selected character pixels **42**. In a typical implementation, the foregoing information is included in an assembled feature vector **30** for access and processing by the character recognition apparatus **170**.

The location of a character image pixel **40**, whether it is a character pixel **42** or a background pixel **44**, can be expressed in terms of an address within a Cartesian coordinate system. Although the placement of the coordinate system's origin over the character image **40** is arbitrary, certain placements have become customary in the art of image processing. According to a configuration known as "orientation one," the origin of a Cartesian coordinate system is located at the upper left pixel in an image. Furthermore, while image pixels to the right of the origin are regarded as having a positive-x address component in accordance with normal mathematical convention, image pixels below the origin are regarded in "orientation one" as having a positive-y address component as opposed to a negative-y component. For purposes of illustration and explanation throughout this description and the accompanying drawings, orientation one is used. FIG. 2 is among the figures including a Cartesian system in orientation one.

There are various alternative methods of establishing the average stroke width $\mathbf{SW_A}$ of a character image character **22**. One illustrative method includes calculating the numeric average of run lengths within the character image character **22** by numerically adding all of the run lengths and dividing by the total number of runs. Where this method yields a non-whole number result, the algorithm can optionally call for the result to be rounded up or down to the nearest whole number. According to another illustrative alternative method, at least one histogram is generated and the run-length value corresponding to the peak within each histogram is established as an average stroke width $\mathbf{SW_A}$. Two alternative approaches incorporating histogram generation are discussed below in conjunction with FIGS. 2a through 2g.

Referring to FIG. 2d, a cumulative histogram **400** indicates along the y-axis the cumulative number of occurrences of a particular run length over all four scan directions shown in FIGS. 2a through 2c and, along the x-axis, run lengths from one pixel to thirty-six pixels. The average stroke width $\mathbf{SW_A}$ is estimated to be the run-length corresponding to the spike **405** in the histogram **400**. In this particular example, a spike **405** in the number of occurrences (i.e., 92) corresponds with a run-length of 5 pixels. Accordingly,

5-pixels is established as the average stroke width **SW_A** of the illustrative character image character **22** of "I." The average stroke width **SW_A** is used to establish a base filter constant for bar extraction, for example. For instance, in the illustrative extraction scans of FIGS. 2h through 2k, the algorithmic bar-extraction scan mode ignores (i.e., does not extract) any horizontal, vertical, 45° diagonal or 315° diagonal run **50h**, **50v**, **50ne** and **50se** that is not a least 1 pixel longer than twice the average stroke width **SW_A**. That is, for purposes of this example, in order to be extracted as a bar **60** or as part of a bar **60**, a run **50** must be at least $2SW_A + 1$ in length. Accordingly, in the present example, because the average stroke width **SW_A** is 5 pixels, a run **50** of character pixels **42** must be at least 11 pixels **42** in length in order to be extracted. Laterally adjacent runs **50** at least as long as the specified minimum length, and typically of substantially equal length, combine to define a bar **60**.

The average stroke width **SW_A** having been determined, algorithmic bar-extraction scans in each of the horizontal, vertical, northeast and southeast directions yield the resultant run representations shown in FIGS. 2h though 2k, respectively. More specifically, when the character "I" is scanned horizontally, two horizontally extending bars **60h**, an upper bar and a lower bar, result. Each horizontally extending bar **60h** is comprised of five laterally adjacent, connected runs **50h**, with each run **50h** meeting the criteria for extraction (i.e., each is at least 11 character pixels **42** in length) as shown in FIG. 2h. Referring to FIG. 2i, the vertical scan yields one vertical bar **60v** that is thirty character pixels **42** long and five pixels **42** wide. Referring to FIGS. 2j and 2k, each diagonal scan yields zero extracted bars **60** because the longest run **50ne/50se** along either diagonal scan is ten character pixels **42** in length (see FIGS. 2b and 2c), one pixel **42** less than the minimum length required for extraction.

In addition to minimum length requirements, a minimum width might also be included among the criteria for extraction. For instance, to be extracted as a bar **60**, a configuration of runs **50** might be required to contain at least three laterally adjacent,

connected runs **50** that meet the minimum length requirement. A suitable minimum bar width parameter would reduce the likelihood that noise on the order of, for example, a single pixel would contribute to a "false extraction."

In alternative implementations, a direction-specific histogram is generated for each direction in which the extraction algorithm scans for runs. In this way, as applied to the current example, an average stroke width **SW**$_A$ is determined for each of the four directions. The average stroke width **SW**$_A$ corresponding to any first particular direction provides a base constant for the extraction of runs extending in a second direction orthogonal to the first direction. As a practical matter, a single character-wide average stroke width **SW**$_A$ is sufficient to generate the desired results. However, since direction-specific average stroke widths **SW**$_A$ may be useful in one or more implementations, reference in made to FIGS. 2e through 2g for illustrative direction-specific histograms **420** relative to the character "I" of FIGS. 2 through 2c. A histogram **420** for each scan direction indicates, along the y-axis, the number of occurrences of a particular run length and, along the x-axis, a set of run lengths measured in character pixels **42**. Unlike the cumulative histogram **400** of FIG. 2d, the peak **425** in each direction-specific histogram corresponds to the average stroke width **SW**$_A$ for the relevant direction. The average direction-specific stroke width **SW**$_A$ for a particular direction is used as a base filter constant for the purpose of extracting runs **50**/bars **60** in the direction orthogonal thereto. In the current example, the direction-specific stroke width **SW**$_A$ indicated by the direction-specific histogram **420** for each of the four scan directions happens to coincide with the cumulative average stroke width **SW**$_A$ established by the cumulative histogram **400** of FIG. 2d. Although such agreement may not always be present, particularly when irregularly configured character image characters **22** are involved, the cumulative average stroke width **SW**$_A$ is typically sufficient to extract the runs **50** and bars **60** desired from an overall character image character **22**.

FIGS. 3 through 3c illustrate a methodology of isolating and extracting lakes.

Referring to FIG. 3, an illustrative character image **20i** includes a character image character **22** "e" comprised of black character pixels **42**. In FIG. 3a, the boundary or edge **45** of the character image **20i** is comprised of edge pixels **47**, which are indicated in gray for ease of identification. The character image **20i** of FIGS. 3 through 3c includes 864 total character image pixels **40** of which 457 pixels are character pixels **42** and 407 are background pixels **44**.

According to one lake extraction method, the character image **20i** is first "complemented." For example, where the character pixels **42** in the original character image **20i** are black and the background pixels **44** white, the colors are reversed so that the character pixels **42** are white and the background pixels **44** are black. As shown in FIG. 3b, when the character image **20i** including the character image character **22** "e" is complemented, what remains are two separate black "connected regions." Each black connected region **70** is comprised of laterally adjacent pixel runs **50** of varying lengths. Next, in general accordance with the illustrative method under consideration, each connected region **70** that touches the image boundary **45** of the character image **20i** is removed (i.e., filtered away and eliminated from consideration). As shown in FIG. 3c, the smaller connected region **70** does not touch the image edge **45** of the character image **20i**, but the larger connected region **70** does. Accordingly, as shown in FIG. 3c, the larger connected region **70** is eliminated from consideration, leaving only the smaller connected region **70** which, by elimination, must be a lake **74**. Once the character image **20i** has been filtered to isolate the lakes **74**, numeric information concerning the lakes **74** is ascertained and added in the appropriate array indices of a feature vector. For instance, one item of information about a lake **74** that may be useful is the address (e.g., x-y coordinates) of its "centroid."

The centroid of a bar, lake or bay may be alternatively defined. However, it is advantageous to treat the centroid of a connected region as analogous to the center of mass of a uniformly dense, two-dimensional mass. A second illustrative definition defines

a centroid as the intersection between a first central pixel run extending in the direction of orientation of the connected region and a second central pixel run extending in the direction orthogonal to that of the first central pixel run. In various aspects, either definition will result in the same point or pixel being identified as the centroid as, for example, in the case of regularly shaped connected regions such as rectangular bars comprised of odd numbers of pixel runs in each of the two directions.

As shown in FIG. 3c, the centroid **80** of the lake **74** was calculated as a "center of mass," and resides at X=14, Y=12 within the character image **20i**. Although those of even minimal skill in physics or image processing know the calculation of the center of mass of an object, or the centroid of a connected region of pixels, a brief explanation of the illustrative method used in the examples throughout this description is warranted. The quantity of lake pixels **75** at each x and y location are summed and then divided by the total number lake pixels **75**. For instance, in FIG. 3c, there are 31 lake pixels **75** distributed with the following x addresses with the product of the lake pixels **75** at each x location and the value of the x location appearing in parentheses: 4 pixels at x=11 (44); 5 pixels at x=12 (60); 5 pixels at each of x = 13 (65); 5 pixels at x=14 (70); 5 pixels at x=15 (75;) 4 pixels at x=16 (64) and 3 pixels at x=17 (51). The summation of the preceding parenthetical quantities equals 429 and 429 divided by 31 lake pixels **75** equals 13.8. Since it is not typically tenable to express positions in fractional pixels, the x and y positions of a centroid are taken to be at the nearest whole number position. A similar summation for the y-positions of the 31 lake pixels **75** in FIG. 3c indicates that the y-location of the centroid **80** is at y = 12. Therefore, the address of the lake centroid **80** is (14,12). Again, although the position of a connected region centroid can be alternatively determined, the various centroids discussed throughout this description were calculated using the foregoing illustrative method.

In various aspects, information about the centroids **80** of bars, lakes, and bays is useful, for example, in establishing the relative, distinguishing orientations and spatial relationships of character features. Consider the character images **20i** including the

character image characters **22** "p," "q," "d" and "b" illustrated in FIGS. 4a through 4d. Each of these character images **20i** is comprised of one bar **60** and one lake **74**. More specifically, but indistinguishably, each is comprised of one vertical bar **60v** and one lake **74**. More information is required in order to distinguish among these character image characters **22**. By providing the locations of the bar centroid **80B** and the lake centroid **80L** for each of these character image characters **22**, the character images **20i** are distinguished from one another. For example, consider the character images **20i** in each of FIGS. 4a-d relative to the superimposed Cartesian coordinate system. As previously discussed, although origin placement is arbitrary as long as consistency is maintained, the origin in each of FIGS. 4a-d is taken at the top left character image pixel **40** in the overall character image **20i** in accordance with "orientation one." The character image characters **22** in FIGS. 4a-d are distinguishable on the basis of the x and y values defining the address of the lake and bar centroids **80L** and **80B** in each of the four character images **20i**. For instance, consider "p" and "q" of FIGS. 4a and 4b. Although in these particular examples, the lake centroid **80L** in each character image **20i** is at (13,13), "p" is distinguishable from "q" on the basis that the address of the bar centroid **80B** in "p" has a lower x-value than the x-value of the lake centroid **80L** in "p," while the x-value of the bar centroid **80B** in "q" is higher than the x-value of the lake centroid **80L** in "q." The x-value distinction is not alone sufficient, however, to distinguish the "p" in FIG. 4a from the "b" in FIG. 4c. However, "p" and "b" are distinguished by observing that the y-value of the bar centroid **80B** in "p" is higher than the y-value of the lake centroid **80L** in "p." Contrarily, in "b" of FIG. 4c, the y-value of the bar centroid **80B** is lower than the y-value of the lake centroid **80L**.

Another character feature important to various implementations of the invention is a bay. According to a set of implementations, bays, like lakes, are extracted by generating the complement of a character image. Unlike a lake, a bay belongs to a connected region of pixels that touches the boundary of the character image. Accordingly,

lakes can be eliminated from consideration by filtering away any connected regions that do not touch a character image boundary. Removal of the lakes in the complemented character image leaves only the connected regions containing bays, if any. The bays are isolated within the connected regions remaining after elimination of the lakes by filtering away pixels runs within the remaining connected regions that touch the character image boundary.

Consideration of the complemented character image **20i** of “e” in FIG. 3b, and FIGS. 3d through 3f, facilitate an appreciation of a bay extraction aspect. As discussed in connection with lake extraction, the complemented character image **20i** of FIG. 3b includes two distinct connected regions **70** comprised of blackened background pixels **44**, each of which pixels **44** has at least one neighbor. When the connected region **70** that does not touch an edge (i.e., the lake **74**) is filtered away, only the single connected region **70** shown in FIG. 3d remains. A subset of connected background pixels **44** within the remaining connected region **70** constitutes a bay **78**.

In a typical aspect, bays **78** are isolated and extracted by filtering pixel runs **50** that touch an image edge **45** out of a connected region **70** that touches and/or includes an image edge **45**. Additionally, each end pixel of a pixel run **50** within a remaining bay **78** typically neighbors a character pixel **42**. Moreover, the configuration, or even the existence, of a bay **78** may depend upon the direction in which an edge-touching connected region **70** is algorithmically scanned to filter away the runs **50** within that connected region **70** that touch an image edge **45**.

An appreciation for the directional dependence of bay configuration is enhanced by reference to FIGS. 3e and 3f. FIG. 3e illustrates the resultant horizontal bay **78h** when the edge-touching connected region **70** remaining in FIG. 3d is algorithmically scanned horizontally to exclude all runs **50** that touch the image boundary **45**. Contrast the configuration of the bay **78h** resulting from the horizontal scan with that resulting from the vertical scan in FIG. 3f. Among other obvious differences in configuration, the

vertical bay **78v** of FIG. 3f includes forty-seven bay pixels **79** to the horizontal bay's seventeen bay pixels **79**.

In a typical implementation, the particular configuration of a bay is less important than, for example, the quantity of bays and their spatial relationships with other extracted features (e.g., other bays, lakes and bars). In the case of the "e" above, although the directions of algorithmic scan resulted in bays **78h** and **78v** of different configuration, there was no difference in the quantity of bays **78** resulting from the two scans. For some character image characters, this will not be the case. That is, for some character image characters, the number of bays identified when the character image is scanned in a first direction will differ from the number of bays identified when that same character image is scanned in a second direction. The quantity of a particular kind of feature (e.g., bays) extracted in each of a plurality of predetermined directions is, in various implementations, among the data included in the feature vector associated with a character image.

An example of directional dependence of feature quantity is considered in conjunction with the character image **20i** of FIGS. 5 and the manipulated representations thereof in FIGS. 5f and 5g. Shown in FIG. 5 is a character image **20i** including the character image character **22** "c." The complement of the character image **20i** in FIG. 5 is shown in FIG. 5a. As illustrated in FIG. 5f, filtering the complement of the character image **20i** of "c" in the horizontal direction to exclude horizontally extending runs **50h** that touch the image boundary **45** yields two bays **78**, an upper horizontal bay **78h** and a lower horizontal bay **78h**. When the character image **20i** of "c" is algorithmically filtered in the vertical direction, as in FIG. 5g, a single bay **78** filling the interior of the "c" from top to bottom is yielded. As with bars **60**, various implementations treat bays **78** as having an orientation depending on the direction of algorithmic scan used to isolate and extract them. Accordingly, a feature vector corresponding to "c" might include indications that the character image **20i** of "c" includes two horizontal bays **78h** and one vertical bay **78v**. FIGS. 5 through 5g are revisited later in this description in connection with an associated character feature vector **30** shown in FIG. 5h.

Before discussing an illustrative feature vector in connection with the character image **20i** in FIGS. 3 through 3j, reference is made to FIGS. 3g through 3j which illustrate bar extraction results for each of four directions in association with the character image character **22** "e." For purposes of illustrating bar extraction in FIGS. 3g through 3j, a 7-pixel average stroke width $\mathbf{SW_A}$ is assumed. Moreover, pixel runs **50** that are at least 2x$\mathbf{SW_A}$ meet the minimum threshold for extraction in each of the four scan directions illustrated.

The horizontal bar-extraction scan of FIG. 3g yielded three horizontal bars **60h**. A first horizontal bar **60h** (the bar in the center) includes five runs **50h**. Each run **50h** is twenty-three character pixels **42** in length for a total of 115 character pixels **42** in the first bar **60h**. Each of the five runs **50h** in the first bar **60h** begins at x = 3 and ends at x=25. The first run **50h** of the first bar **60h** has a y-value of 15, while the second through fifth runs **50h** have y-values of 16, 17, 18 and 19, respectively.

The location of the first bar **60h**, as with any connected region **70**, may be additionally or alternatively expressed in terms of a "bounding box" defined by the x-y addresses of four character image pixels **40** at the corners of the box. For instance, the first bar **60h** in FIG. 3g could be expressed in terms of the four character pixels **42** at (3,15); (25,15); (3,19) and (25,19). Although the location of any type of connected region **70** (e.g., bar, lake or bay) can in theory be indicated by a bounding box, rectangular connected regions **70** (i.e. bars **60**) are particularly well suited for such identification for obvious reasons. The runs **50** within a connected region **70** can also be located by the number of the scan line **55** in the direction-specific run representation corresponding to a scan direction or as a run number within an identified connected region **70**, for example. For instance, the location and size of the top run **50** in the first bar **60** of FIG. 3g might be alternatively expressed as (i) "scan line 15, begin 3, end 25;" (ii) "scan line 15, begin 3, length 23;" or "bar 1, run 1, begin 3, end 25, length 23," for example. The same run **50** could also be identified as simply as "begin (3,15); end (25,15)." The particular manner in

which run information is expressed for inclusion in a feature vector, for example, is of no significance.

Turning to the vertical bar-extraction scan of FIG. 3h, two vertical bars **60v** were yielded. The northeast (45 degree) scan resulted in the single bar **60ne** shown in FIG. 3i while the southeast scan resulted in the two bars **60se** shown in FIG. 3j.

As the features of a particular character image **20i** are extracted, a profile of the image features is compiled in an assembled feature vector. In various aspects, the feature vector is an array that organizes resolved character-attribute data according to a predetermined set of standards.

Referring to FIG. 6, an illustrative partial assembled feature vector **30** corresponding to the character image character **22** "e" in FIGS. 3 through 3j is shown. The feature vector **30** of FIG. 6 includes data relating to the bars **60**, lakes **74** and bays **78** for which extraction is illustrated in FIGS. 3b through 3j. The feature vector **30** of FIG. 6 being illustrative only, it is to be understood that feature vectors **30** can be variously configured and include various data. For instance, a simpler feature vector **30** than that shown in FIG. 6 might include only the quantities of each of bars **60**, lakes **74** and bays **78** yielded from each direction of algorithmic scan of a character image character **22** and, perhaps, the spatial relationships among them. Information as to the spatial relationships among extracted character features is at least advantageous in determining the identity of a character image character **22**. In some instances spatial relationships become more critical to character identity as, for example, in the illustrative case of "p," "q," "b" and "d," previously discussed, while in other instances a character image character **22** is uniquely identifiable on the basis of character feature quantities alone.

Once a feature vector **30** is assembled, it is rendered accessible to the character recognition apparatus **170**, which is programmed to resolve the feature vector **30** and identify the character image character **22** with which the assembled feature vector **30** is associated. As previously discussed, in one alternative implementation, the character

recognition apparatus **170** comprises a character dictionary **180** and a comparator unit **200** as shown in FIG. 1. The comparator unit **200** is adapted to receive assembled feature vectors **30** from one or more feature extraction units **150**. Once the feature vector **30** corresponding to a particular character image **20i** has been assembled, either fully or to the extent possible, the feature vector **30** is rendered accessible to the comparator unit **200**. The comparator unit **200** compares the assembled feature vector **30** to standardized character profiles contained within the character dictionary **180** containing a plurality of output character candidates. The output character candidate corresponding to the standardized character profile that most closely resembles the assembled image feature vector **30** is selected as the output character.

For purposes of comparing an illustrative assembled feature vector **30** to a standardized character profile in a character dictionary **180**, considered the character image **20i** of “c” in FIG. 5 as it is algorithmically scanned in FIGS. 5a through 5g to extract only the quantities of bars **60**, lakes **74** and bays **78** ascertainable from each direction indicated. FIG. 5a shows the complement of the character image **20i** in FIG. 5. Bar-extraction scans for each of four directions are shown in FIGS. 5b through 5e. For purposes of bar extraction, the assumed average stroke width $\mathbf{SW_A}$ is 7-pixels and the extraction threshold indicates that a run **50** must be at least 2x$\mathbf{SW_A}$ + 1 in length in order to be extracted. A horizontal bar-extraction scan is shown in FIG. 5b as yielding two horizontal bars **60h**. The vertical scan of FIG. 5c resulted in a single extracted bar **60v**. In FIG. 5d, a 45-degree (i.e., northeast) bar-extraction scan yielded a single northeast bar **60ne**. The southeast bar-extraction scan of FIG. 5e indicates a single southeast bar **60se**.

Turning to bay and lake extraction, the complemented image **20i** of FIG. 5a indicates no connected region **70** that does not touch the edge **45**; there is only a single connected region **70** that touches the edge **45**. Therefore, no lakes are present in the character image **20i**. As previously discussed, FIG. 5f illustrates the results of a

horizontal bay extraction scan including the exclusion of all horizontal runs **50** that touch the edge **45**. As shown, the horizontal bay-extraction scan yielded two separate horizontal bays **78h**. In contrast, the vertical bay-extraction scan results shown in FIG. 5g indicate that there is only a single vertical bay **78v**.

Referring to FIG. 5h, an illustrative assembled feature vector **30** incorporating the bar, lake and bay data extracted from the character image **20i** in FIGS. 5 through 5g is shown. The illustrative assembled feature vector **30** includes categorized data indicating that extracted from the input character image **20i** were two horizontal bars, one vertical bar, one southeast (315 degree) bar, one northeast (45 degree) bar, zero lakes, two vertical bays and one horizontal bay.

Referring to FIG. 7, a portion of an illustrative character dictionary **180** includes a plurality of output character candidates **182** and, in association with each output character candidate **182**, a standard profile **185** including a set of categorized, standardized character features **188** indicative of the identity of the associated output character candidate **182**. Referring to the assembled feature vector **30** of FIG. 5h and the partial character dictionary **180** of FIG. 7, the output character candidate **182** having a standardized profile **185** including data most closely resembling the data of the assembled feature vector **30** of FIG. 5h is the output character candidate "C." Accordingly, "C" would be selected as the recognized output character.

An additional observation worthy of note in connection with the partial character dictionary **180** of FIG. 7 is that some characters may not be distinguishable solely on the basis of bar, bay and lake quantities. Consider the two sets of characters including "L" and "T" and "M" and "W." Based solely on the partial standard profiles **185** presented in FIG. 7, "L" is indistinguishable from "T" and "M" is indistinguishable from "W." These cases present two illustrative examples of the need for further information in both the character dictionary **180** and the assembled feature vectors corresponding to "L," "T," "M" and "W." Such further information could include, for instance, scan line

numbers, run locations within an x-y coordinate system, run locations within numbered scan lines, bounding-box coordinates and bay centroid addresses, by way of non-limiting example. The more detail included in a feature vector, the more likely the positive identification of the object character to which it corresponds.

As previously discussed, the character recognition apparatus **170** in various alternative implementations includes a trainable neural network **300**. FIG. 8 depicts an illustrative training session in which a neural network **300** is being trained to recognize numerous variations of the character "A." As shown, the neural network **300** is fed training character image inputs **20iT**. For each training character image input **20iT**, a feature vector **30** is assembled and rendered accessible to the neural network **300**. For each feature vector **30** communicated to the neural network **300**, the neural network **300** is instructed as to the desired identification of the object character (not shown) corresponding to the training character image input **20iT** from which the feature vector **30** was derived. Through such repetitive exposure to multiple variations of a character, the neural network **300** "learns by example."

FIG. 9 is a flowchart representation of an illustrative character recognition method relying on the extraction of bars **60**, lakes **74** and bays **78** from a character image **20i**.

Referring to step **510**, a classification system is predefined according to which each alphanumeric character of a set of alphanumeric characters is identifiable at least in part on the basis of the presence and/or absence within the character of each character feature type of a predetermined set of character feature types. Among the predetermined set of character feature types are bars, lakes and bays.

In accordance with step **520**, an image of an object character is captured and stored as a character image in a data storage device. Feature extraction apparatus is/are provided at step **530**. The feature extraction apparatus is/are communicatively linked to the data storage device and adapted to (i) algorithmically scan the character image along each scan angle of a predetermined set of scan angles in order to extract

character features ascertainable along that scan angle and (ii) assemble a feature vector corresponding to the character image, the feature vector including data indicative of at least the quantity of each character feature type present in the character image along each scan angle.

Step **540** and **545** call for communicating the character image to the feature extraction apparatus and causing the feature extraction apparatus to assemble a feature vector corresponding to the character image.

At step **550**, character recognition apparatus is/are provided. The character recognition apparatus is/are adapted to recognize a character corresponding to an assembled feature vector at least partially on the basis of the quantity of each of (i) bars; (ii) lakes and (iii) bays indicated in the feature vector and to provide an output indicative of the recognized character.

At step **560**, the feature vector assembled by the feature extraction apparatus is rendered accessible to the character recognition apparatus for identification (i.e., recognition) of the corresponding object character.

The foregoing is considered to be illustrative of the principles of the invention. For instance, the use throughout this specification of English-alphabet letters as representative characters should not be interpreted as a limitation on the scope of application to English-alphabet and Arabic number characters; the principals of the invention are equally applicable to characters and symbols of any language and may, in fact, find applications beyond character recognition. Furthermore, since modifications and changes to various aspects and implementations will occur to those skilled in the art without departing from the scope and spirit of the invention, it is to be understood that the foregoing does not limit the invention as expressed in the appended claims to the exact construction, implementations and versions shown and described.